Demonstrating Biological Principles Efficiently & Effectively:
The Overhead Is More than Just a Lighted Chalkboard

LAURA M. BARDEN-GABBEI

The overhead projector is an excellent tool for teachers at both the high school and college level. Teachers often use it to display class notes as they monitor students' actions and reactions to the concepts being presented and discussed, to display diagrams and figures too complex to draw on the chalkboard, and more recently to display computer images through an LCD panel. But the overhead is an underutilized tool. In addition to being used as a lighted chalkboard or an enlarged television screen, it can also be used as a means of projecting simple demonstrations of biological principles. Classroom demonstrations are often conducted on a desktop at the front or back of a classroom, thus limiting the number of students who can actually see what is happening. This is particularly problematic for large classes. Using the overhead to display demonstrations provides all students in the class the opportunity to see the demonstration regardless of their seat location. It also prevents congestion in the demonstration area as students move to gain a better vantage point (or hide to have private conversations). Among the concepts which can be easily demonstrated with just a few simple and inexpensive props are endocytosis and exocytosis, mitosis and meiosis, protein configuration, and relative sizes of objects such as egg and sperm. I have used these demonstrations in a large university level introductory non-majors biology class (over 150 students) but they could be used equally as effectively with smaller classes at both the high school and college level. These demonstrations were designed to assist students in visualizing the dynamic processes occurring in their own bodies and increase their level of conceptual understanding. My students' reactions to them have been quite positive and, more importantly, use of the demonstrations has increased my students' understanding of the concepts while at the same time significantly reducing the amount of lecture time and notes necessary to describe the concepts verbally.

Endocytosis & Exocytosis: Magnetic Marbles Work Wonders

Endocytosis and exocytosis are processes through which materials too large to move through cell pores or active transport are taken into (endo) or out of (exo) the cell. The process is a relatively simple one, but students at the high school and freshman college level often have difficulty visualizing the process. Though most textbooks have nice diagrams depicting the process, many students still fail to appreciate how the

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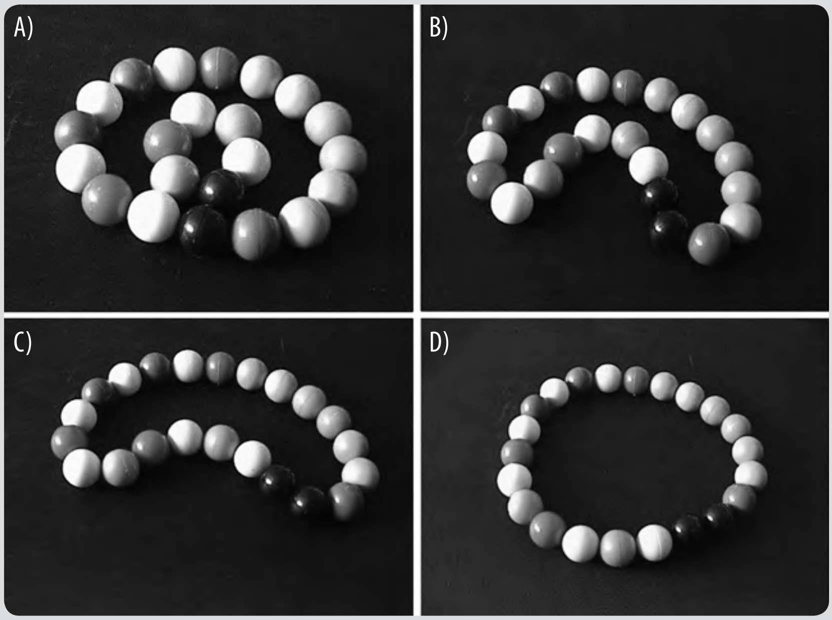
invaginating cell membrane (endocytosis) fuses to form a vesicle on the inside of the cell leaving the cell membrane intact. They also have difficulty imagining how through secretion (exocytosis) the vesicle membrane fuses with the cell membrane becoming part of the membrane while secreting its contents. A simple demonstration using inexpensive round, marble-sized, plastic-coated magnets (henceforth referred to as magnetic marbles) provides students the opportunity to visualize this process quickly (see Figure 1).

Figure 1. Magnetic Marbles

Materials Needed

This demonstration requires a set of magnetic marbles. These marbles usually come in sets of 15 or 20 marbles of assorted colors. They can be purchased at most craft and hobby stores, some discount department stores (e.g., Target, Kmart, etc.), and some science mail order catalogs (usually in the physics category, e.g., Carolina Science and Math Catalog, Frey Scientific, etc.). Having an assortment of colors can be helpful during the demonstration, as described in the next section.

Figure 2. Exocytosis using Magnetic Marbles



Demonstration

In order to familiarize students with the materials, I show them a string of the multicolored magnetic marbles before placing them on the overhead. Figure 2 shows how the process of exocytosis works using the model. Two rings of magnetic marbles are made and placed on the overhead. The larger outer ring represents the cell membrane and the smaller inner ring represents the membrane surrounding a vesicle. When the two rings are brought together, the magnets become attracted and very quickly the two rings become one. This shows the students how the contents of the inner vesicle end up on the outside of the cell. In order to provide my students context for the process, I generally suggest the vesicle contains a hormone previously discussed in the course, e.g., gonadotropic-releasing hormone (which is made in the hypothalamus but regulates hormone production in the gonads).

The magnetic marbles can be used equally well to demonstrate endocytosis (both phagocytosis and pinocytosis). A simple reversal of the process shown in Figure 2 is used. A single large ring of magnetic marbles is used. Then, using a finger or a small object, the ring can be pushed in, invaginated, until magnets from different sections of the ring become attracted to one another forming a smaller inner vesicle, leaving behind an intact cell membrane.

One drawback with this demonstration is when approaching magnets repel one another. Since high school and college students are generally familiar with magnetic attractive and repulsive properties, this does not cause undue problems. If you use multicolor magnetic marbles, then with a little practice ahead of time, you can note which magnets are properly oriented and avoid this problem.

I have found that this demonstration reduces students' confusion, increases their understanding of the biological principle, reduces the amount of time needed to discuss the basic concepts of endo- and exocytosis, and provides the basis for understanding more complex ideas about cell membrane function more quickly and thoroughly. In my introductory non-majors freshman biology course, even the graduate teaching assistants who sit in on the class to assist with a variety of tasks have commented that this demonstration helped them better visualize a process with which they were already quite familiar!

Mitosis & Meiosis: Pipe Cleaner Chromatids

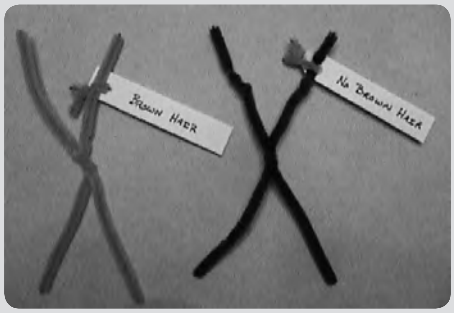
Mitosis and meiosis tend to be very difficult topics for both high school and college students in introductory biology courses. A variety of tools are available to assist teachers in making these concepts more accessible, including labs, short videotapes, and text diagrams. However, many students still find the concepts hard to visualize. The typical lecture, which includes drawing the cell with two or three chromosome pairs at different stages of the process

and possibly a videotape presentation, is not sufficient for most students. They need more exposure. To complement the lecture, labs, and videotapes, a simple demonstration using colored pipe cleaners can be added.

Materials Needed

The only materials needed for this demonstration are pipe cleaners (color does not matter). Optional materials you might want to use if you teach multiple sections of the same course include non-drying clay or Velcro™ and glue or tape. Pipe cleaners are the main item needed since they are the item being used as an analogy for condensed chromosomes. (Note: If you have an ELMO instead of an overhead projector, you might prefer a variety of different colored pipe cleaners, though white is sufficient.) The pipe cleaners can be cut to different lengths and centromeres added at different locations along their lengths to mimic actual chromosomes. The centromeres can be represented in a number of ways: by a twist which connects two Pipe Cleaners (i.e., chromatids), by a small amount of nondrying clay on each pipe cleaner, or by Velcro™ which is taped or glued to each pipe cleaner. Of these, Velcro™ tends to work the best if you plan to reuse the materials over many lecture sections. Otherwise, twisting two pipe cleaners together to represent two attached chromatids works fine (see Figure 3). The continual untwisting and retwisting of the pipe cleaners through the demonstration tends to wear out the pipe cleaner and takes time but not at a significant level. Using clay works quite well so long as it is not left on the hot overhead too long–the clay can get quite messy. Small Velcro™ strips glued to complimentary chromatids eliminates the problems associated with the other two methods. Velcro™ strips can be purchased at many craft, hobby, and discount department stores.

Figure 3. Pipe Cleaner Chromosomes.
Homologous pairs exhibiting different alleles: brown hair color vs. no brown hair color.



Demonstration

When introducing the topic of mitosis or meiosis for the first time, I tend to use these models to provide an overview of what happens to the chromosomes before actually describing the phases (i.e., interphase, prophase, metaphase, anaphase, and telophase). This way the students get to see how chromosomes must align so that they can be separated in an orderly fashion, thus increasing the chances of accurate replication. Then when actually describing the stages, I use the models once again in conjunction with drawings and other overhead transparencies. I have found this demonstration works particularly well when I devote one overhead to manipulating the model chromosomes and a second overhead to writing notes.

To add a bit of variation to this activity, I add labels to represent specific traits or alleles for a trait. Labels can be as simple as small pieces of pipe cleaner or as elaborate as strips of overhead transparencies on which the trait or allele is written. As with the centromeres, the labels can be added by twisting small pipe cleaner pieces onto the chromatids or by attaching Velcro™ on both the labeled strip of overhead transparency and the corresponding chromatid. Whichever form you choose, the students need to be informed which trait you are examining. I tend to use hair color since multiple genes are required for its expression. I generally pick red hair color and brown hair color since they are found on different chromosomes. To do this demonstration, the two sets of chromosomes to be used for hair color are identified by their length and location of the centromere. Then, one homolog of each homologous pair is assigned as expressing the color (either red or brown), and the other pair is assigned as not expressing the color. In this way, the gametes produced through the process of meiosis could carry any of the following combinations of hair color: red and brown, red but no brown, brown but no red, and neither red nor brown. This sets up a very nice two trait cross problem. I have found labeled pipe cleaners particularly helpful in getting students to relate the ideas of meiosis with Mendelian Genetics and inheritance patterns.

Students' responses to the pipe cleaners have been quite positive. Many of the students who have difficulty following book and lecture diagrams, find the pipe cleaner demonstration quite helpful. A few of my students have even copied the materials to make a model set for themselves in order to practice manipulating them at home while studying.

Enzyme Function Using 3-D Puzzles

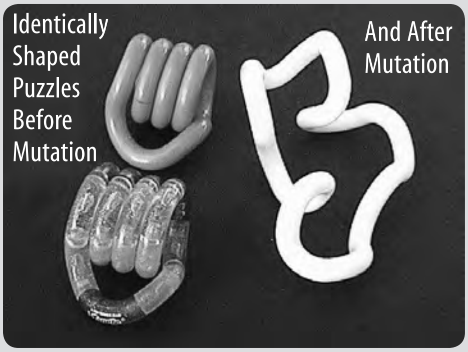
The three-dimensional nature of proteins and the importance of the shape to enzyme function is often not well understood by students. Most students seem to understand the primary structure of proteins, i.e., the amino acid sequence, and to be able to picture a string of amino acids in a chain. However, students have more difficulty picturing the secondary and tertiary structures of proteins, i.e., the steric relationships of proximal and distal amino acid residues in the amino acid chain. This leads to difficulty as students try to picture the changes in the 3-D shape of enzymes due to mutations. Students often do not see how a change in the amino acid sequence, especially when the change is a single amino acid in a chain of thousands of amino acids, could possibly render an enzyme non-functional. Since much of this information is now included in courses that do not have a chemistry prerequisite, students are at an even greater disadvantage to understanding such complex chemical issues. A simple 3-D puzzle can be used as an analogy for an enzyme in order to simplify the concept for introductory students.

Materials Needed

Two 3-D tangle puzzles (see Figure 4) are needed. These can be obtained in many craft, hobby, and specialty toy stores (especially those that sell games for the office). Most of the puzzles I have obtained I have found in science museums and at conferences. You may also be able to obtain them through one of many Web sites, (e.g., http://www.officeplayground.com/tangle.html). To find additional Web sites, you may do a search on tangle puzzle. To start the class discussion, the two puzzles should be configured the same way so that they appear identical in shape.

Figure 4. Tangle Puzzle examples

Figure 5. Tangle Puzzle representing 3-D enzymes



Demonstration

When discussing mutations in my non-majors introductory biology course, my students often question how a change in a single amino acid could cause such problems as sickle cell anemia. Since few of these students have any background in chemistry beyond what they learned in their introductory high school biology course or eighth grade science course, discussing the intricacies of secondary, tertiary, and quaternary structures of proteins is not feasible. The students do accept that some amino acids are positively charged, some are negatively charged, and some are uncharged at physiological pH. Most also have the prior knowledge that like charged particles repel one another while unlike charged particles (i.e., opposites) attract. Using the models, I point out a spot where two parts of the model are quite close together and have students imagine that the molecules that are closest together are of opposite charge. Then I ask them what would happen if we changed one of those two amino acids so that the two were like charged instead and, therefore, repelled one another (see Figure 5). The students' ideas of what would happen are confirmed as I alter one of the two tangle puzzles by pulling it out of shape (see Figure 5). Many of my students are curious about the amino acids that might be involved, i.e. they want some proof. So, I then follow this with a discussion of glutamate (negatively charged at physiologic pH) and lysine (positively charged at physiologic pH). Using the m-RNA codon chart in their book, we examine the differences in the codons for each of these two amino acids: for glutamate the codons are either GAA or GAG while the codons for lysine are AAA or AAG. In both cases, the codon sequence is just one amino acid different. We also discuss the changes in the amino acid sequence for sickle cell anemia (i.e., a change from glutamic acid in the normal Hemoglobin A for valine in the sickle cell Hemoglobin S).

The demonstration usually produces audible positive sighs and exclamations from students as they visualize the changes in the shapes of the molecules. Though the change in the puzzle's shape is more drastic than what is likely to occur in most actual proteins, the point is made and the students recognize the problems that some mutations may have in enzymatic function.

Relative Size: Clay Models of Eggs & Sperm

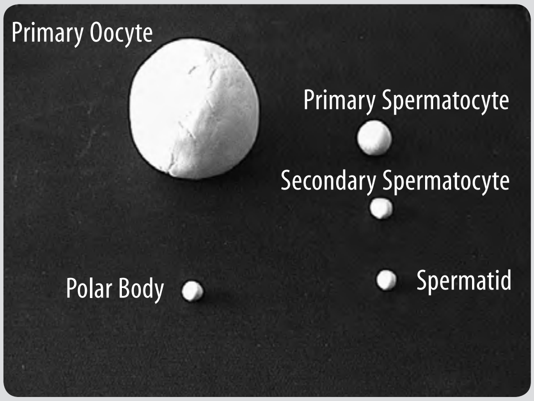
Often in biology we discuss differences in relative size of objects, but the sizes of the actual objects are microscopic. Students tend to have difficulty imagining the size of objects that are smaller than a millimeter in diameter, much less objects that are truly microscopic. To say that one microscopic object is larger than another is often not very helpful. One of the sets of objects that students have particular difficulty imagining with respect to size are human egg, polar body, and sperm. As part of our curriculum, I spend much time elaborating upon the relatively large size of the egg and the need for it to retain as much of the cellular materials and organelles as possible. I discuss the role of the polar bodies and I also discuss the reasons why the oocyte produces one egg and three polar bodies but the spermatocyte produces four sperm. Students generally have difficulty understanding these issues. Underlying their confusion is their lack of ability to imagine the different sizes of the objects. To assist them with this underlying problem, I developed a simple demonstration to show relative size of the different cells.

Materials Needed

For this demonstration you will need a container of modeling clay. I used Crayola® Modeling Clay because it is light and dries to form a hard, lightweight, but almost unbreakable model set. However, any modeling clay that dries to form a hard model would work. To form the models, I simply created balls of clay of varying sizes to represent each of the cell types. For the process of

spermatogenesis, I made models of the primary and secondary spermatocytes and the spermatids. Starting with a small piece of clay about two-thirds the diameter of a dime, I made a ball to represent the primary spermatocyte. Then I made two balls about half that size to represent the secondary spermatocytes. Finally, I made four balls each about half the size of the secondary spermatocytes to represent the spermatids. This is rather straightforward for the students. For the process of oogenesis, I made a rather exaggerated model of the primary oocyte and first polar body. I made the primary oocyte hollow so that all other cell models would fit inside it. Also, since the models were placed on the overhead, the large oocyte "ball" would be less likely to roll off the overhead. I then made a very tiny polar body, about the size of one of the spermatids (see Figure 6) .

Figure 6. Relative sizes



Demonstration

The first topic we discuss in our non-majors introductory biology course is human reproduction and development. Since this topic includes such issues as pregnancy and sexually transmitted diseases (STDs), it is of great interest to our student population of mostly traditional college-aged students away from home for the first time. The concepts of spermatogenesis and oogenesis are a bit less intriguing and more confusing than the general topics of human reproduction and STDs. As mentioned above, one of the more complicating issues is the issue of relative size. When I started using the models to give students a sense of how different in size the sperm was from the egg and the egg was from the polar body, other issues related to cell nutrition became less difficult. I was, in fact, quite surprised at how much the size issue of the different cells complicated the concepts for the students and how, once they had a sense of the differences, they were able to focus on more important concepts such as production of unique offspring and zygote survival prior to implantation.

Conclusion

Each of these demonstrations takes less than five minutes. I have found that by using them, I have reduced the amount of time needed to verbally explain the principles by at least half. Although newer and fancier technologies are becoming increasingly available to teachers in their classroom—computers with LCD panels, ELMOs, PowerPoint, the World Wide Web, etc.,—older, less expensive, and more widely-available technologies, such as the overhead, are often not used to their maximum potential. They can also provide opportunities for effective and efficient demonstrations that can significantly enhance students' understanding of biological principles.

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